# Conceptual Design Report

# Inelastic X-ray Scattering CAT

September 2002

# Table of Contents

# 1 Scientific Objective of the IXS CAT

Inelastic x-ray scattering (IXS) experiments require highly complex set-ups, with high-resolution secondary monochromators, back-scattering analyzers and very low count rates. Even at the 100 meV resolution level, these requirements make time-sharing with other experiments extremely inefficient. A large amount of beamtime is wasted in initial set-up in each experimental period, and inevitably, compromises are made with the beamline optics, which prevent the most efficient use being made of the source. In addition, such time-sharing practices restrict the technique to the small fraction of the (x-ray) community willing or able to construct such an apparatus. At the very high-resolution (few meV) level, time-sharing is totally impracticable and only a dedicated instrument with associated beamline scientist(s), such as exists at the ESRF (France) and SPring-8 (Japan), has any chance of success. As a result of these considerations, IXS-CAT was formed, to design, build and operate a beamline focussed on this single technique. The goal is to produce a reliable, state-of-the-art, user-friendly beamline that would be made available to a wide community.

IXS-CAT members come both from the existing inelastic x-ray scattering community and from the broader scientific community that would like to have access to such an instrument, but lack the expertise, or resources to operate one. They share the common belief that inelastic x-ray scattering can address some of the important problems in their fields. As a result, IXS-CAT has an extremely broad scientific program; ranging from condensed matter physics, to polymer science to biology. The CAT members bring significant resources to the consortium. These include especially, optics and instrumentation development from the Argonne groups, and the long expertise in inelastic x-ray scattering from some of the pioneers in the field. Existing funding consists of $900,000 from the NSF over 3 years to build the high-resolution instrument (HERIX), matched by $550,000 from member institutions. In addition, we have $5,000,000 from the DOE (over 5 years) for the beamline and the medium resolution instrument (MERIX), and commitments from the APS for the undulators, vacuum chambers and front ends. Finally, the APS will be providing significant assistance in the design, procurement and operational aspects of the CAT through the assignment of APS personnel to IXS-CAT responsibilities.

## 1.1 Scientific Case

A given system is defined by its static structure and its dynamical behavior. The former is probed most directly through elastic scattering techniques, while the latter yields to inelastic scattering experiments.

To date, the vast majority of x-ray scattering work has been energy integrating and has measured the quasi-elastic scattering, thus losing most of the dynamical information. However, understanding the dynamics of a system is crucial from a number of perspectives: From a hard condensed matter viewpoint, a given system is completely described by its ground state (the ‘vacuum’ in high energy parlance) and the excitations from the ground state (the 'particles' and their interactions). From a soft condensed matter perspective the propagation of sound waves and other density fluctuations determine the response of the system to time varying probes – a key aspect of their material properties. Finally, in biology, understanding the vibrational modes of biological molecules is as central to the understanding of their function as determining their structure.

Inelastic (energy-resolved) x-ray scattering explicitly recovers much of this dynamical information, offering a number of strengths relative to the more well established inelastic techniques. However, it also places exacting demands on the x-ray source, because of the complementary requirements of high energy resolution and a useful incident flux. Nevertheless, the technique has been slowly maturing over the past three decades. Further, in the past five years, this pace has increased with the construction and operation of dedicated inelastic x-ray scattering beamlines at various synchrotrons around the world, notably at the European Synchrotron Radiation Facility (ESRF, France) and the National Synchrotron Light Source (NSLS, USA) and recently Spring-8 (Japan).

The scientific case for such a beamline is an extremely varied one. The technique offers unique insights into the dynamics of soft condensed matter systems; such as polymers, biological systems, including proteins and membranes, and hard condensed matter systems; including electron dynamics in strongly correlated systems, semiconductors and novel electronic materials, and ion dynamics in solids, liquids and glasses, especially in confined geometries, thin films and extreme environments such as high pressure. As such, the beamline would make significant contributions to a range of the most interesting and exciting problems in science today.

In order to successfully accommodate this varied scientific program, and consequent range of x-ray experience of the users, the beamline will be designed and operated as a user friendly, robust set of instruments. The instruments will remain in place to be continually improved upon, rather than repeatedly being swapped in and out of the experimental hutch. Our role model for this approach is the reactor-based triple-axis spectrometer, which provides a "workhorse"-type instrument for scientists to arrive with their sample, place it in the spectrometer and begin taking data almost immediately.

In this report, we outline how we plan to accomplish this goal. It is envisaged that the beamline will consist of two components, each dedicated to a different regime of excitations. One spectrometer will focus on very high resolution work, with energy resolutions in the sub-meV regime (HERIX). This spectrometer will represent the state-of-the-art, with the highest resolution in the world and significant projected flux increases, relative to the beamline at the ESRF. It will carry out seminal work in the study of dynamics in systems such as high temperature superconductors, solids under high pressure, proteins and polymers.

The second spectrometer will be optimized for the study of higher-energy excitations, with resolutions in the 0.05-1eV range (MERIX). Here studies will be carried out on excitations in electronic materials such as the colossal magneto-resistance manganites, high-temperature superconductors, semiconductors and other novel materials, including the $C_{60}$-based conductors and Mott-Hubbard insulators. In addition, this spectrometer will be optimized to take advantage of the recent discovery of resonant enhancements in the inelastic cross-section.

These two components of the CAT will be designed and operated as essentially separate beamlines, with independently optimized undulators, monochromators and spectrometers. To switch from MERIX to HERIX we will be expecting APS to swap the undulators in the straight section. We expect to operate each instrument for periods of three months at a stretch and perform the swap of the devices during regular maintenance cycles.

## 1.2 Other Dedicated Inelastic X-ray Scattering Beamlines

A number of dedicated inelastic x-ray scattering beamlines have been built at various synchrotrons around the world. Presently, beamline X21 at the National Synchrotron Light Source is the only beamline in the US dedicated to a scientific program of inelastic x-ray scattering. This program is focused on the study of electronic excitations with total energy resolution on the order of 1 eV.

Currently, the ESRF has two beamlines, ID-16 and ID-28 that are dedicated IXS instruments for meV type experiments. These two beamlines have been enormously successful. Recently, ID16 has also started a 100 meV to 1 eV -type program. In addition, ID12A is used for resonant inelastic scattering studies of magnetic materials, and ID15B is used in high-resolution Compton scattering. Finally, ID18 is the nuclear resonant beamline, on which phonon density of state measurements are performed with meV resolution. In addition one beamline ID-26 has allocated 50% of its time for IXS experiements.

At SPring-8, a dedicated beamline for meV type experiments has been commissioned and a part time 0.1 eV to 1 eV instrument is in operation. There are a further two dedicated beamlines for 0.1 eV to 1 eV type experiments which are under construction. There are also dedicated high-resolution Compton scattering and magnetic Compton scattering beamlines.

In contrast, to date there is only a single beamline at the APS, sector 3 (SRI-CAT), which is dedicated to inelastic scattering techniques. This beamline is shared between meV type experiments, and phonon density-of-state measurements using nuclear resonance techniques, though its primary mission has been optics development. Indeed many of the advances proposed here for IXS-CAT arose from work at sector 3. It is expected that this will continue in the future and that sector 3 will work on high-efficiency, high-resolution optics for inelastic x-ray scattering. Indeed, a close working relationship has already been established between IXS-CAT and 3ID personnel in SRI-CAT.

## 2. Rationale for the Choice of Insertion Devices

The tunability of undulators are largely determined by the magnetic period, and the minimum achievable gap. It is now possible to reduce the gap to 8.5 mm at the APS, despite limitations of beam lifetime and engineering challenges involving undulator vacuum chambers. Discussions with the ID group and accelerator physicists at the APS indicate that a minimum magnet gap (MMG) of 7.5 mm will be possible in the near future, and we have based our projections on this value. Furthermore, there is a possibility to extend the length of the ID straight section to 7.5 or 10 m, which may accommodate 3 or 4 undulators in tandem.

Current undulator technology provides two different approaches: i) permanent magnet devices outside of the vacuum chamber, ii) permanent magnet devices inside the vacuum chamber. In addition, there are two other options on the horizon: iii) superconducting undulators, and iv) adjustable period undulators. The permanent magnet devices outside of the vacuum chamber has been adopted at the APS for most of the devices, except the electromagnetic devices for polarization-manipulating-undulators. The second approach has been adopted at the SPring-8 facility in Japan. ESRF largely works with permanent magnet devices outside the vacuum chambers, but they do have the capability of employing "in-vacuum" devices. The superconducting undulator, which provides, by far, the highest magnetic field for a given gap and period, is still an unproven technology, although it has shown to be technically feasible with larger period wigglers placed at many low-energy synchrotron radiation sources, including NSLS. The last possibility is at the moment just an idea, but if it turns out to be feasible, it will be the best solution as discussed below.

After consulting with the local experts at the APS, we made our conceptual plan according to the first approach, and optimized the devices by assuming a lower gap of 7.5 mm. This option also allows a quick exchange of undulators. We have provisionally selected two types of devices with a period of 33 mm, and 15 mm. The final decision on undulator period will be made after a three-dimensional optimization of the magnetic field strength versus magnet dimensions. The tunability curves for a series of devices are given in Figure 1(a) for comparison purposes.

The choice of the undulator for MERIX program is determined by the required energy range of 5-12 keV in the first harmonics. In this regard, all three devices considered with periods of 33, 30 and 27 mm can accomplish this task. However, if the upper limit for the front-end heat load is 20 kW, then undulators with a period of 30 mm will be chosen. The total power corresponding to each energy is given in Figure 1(b). The net flux difference between the 27 and 33 mm devices is somewhere between 30-60 %, as shown in Figure 1(a). However, the 33 mm period provides more photons per unit power in the 5-10 keV range. For this reason, we may simply choose to go with standard undulator A with a 33 mm period, which may be obtained from undulators that are already available or become available, as the other beamlines move toward specialized undulators.

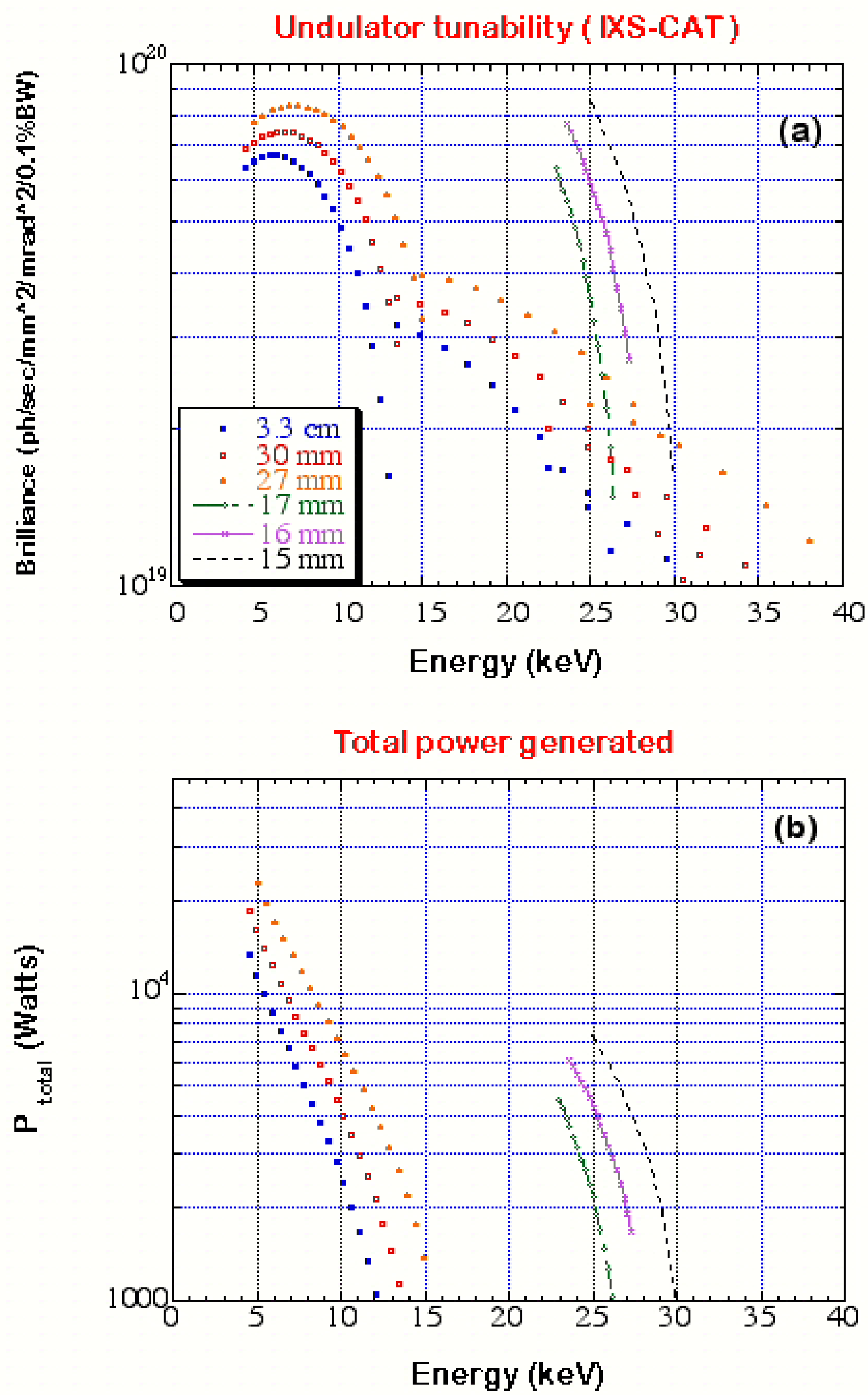



Figure 1 (a) The tunability of undulators with various periods (b) total power generated for the same undulators as a function of energy in the first harmonics. The calculations are based on the 9.6 m long device at a ring current of 100 mA.

The choice for the undulator for HERIX program is based on calculations of different undulator characteristics. The exact energy for Si (13 13 13) back-reflection is 25.701 keV, and the undulator that gets there with the most flux is the 15 mm device. However, all three devices shown in Figure 2 have extremely limited tunability range, and hence limit future options. If the choice of variable undulator period becomes available, than the risk factor diminishes. Also, if the progress with superconducting undulator is found to be satisfactory, we would like that solution, as well. The ideal undulator for HERIX is a device with relatively flat tunability curve between 20 and 30 keV, with a brightness in the $10^{20}$ ph/sec/mm$^2$/mrad$^2$/0.1%BW range.

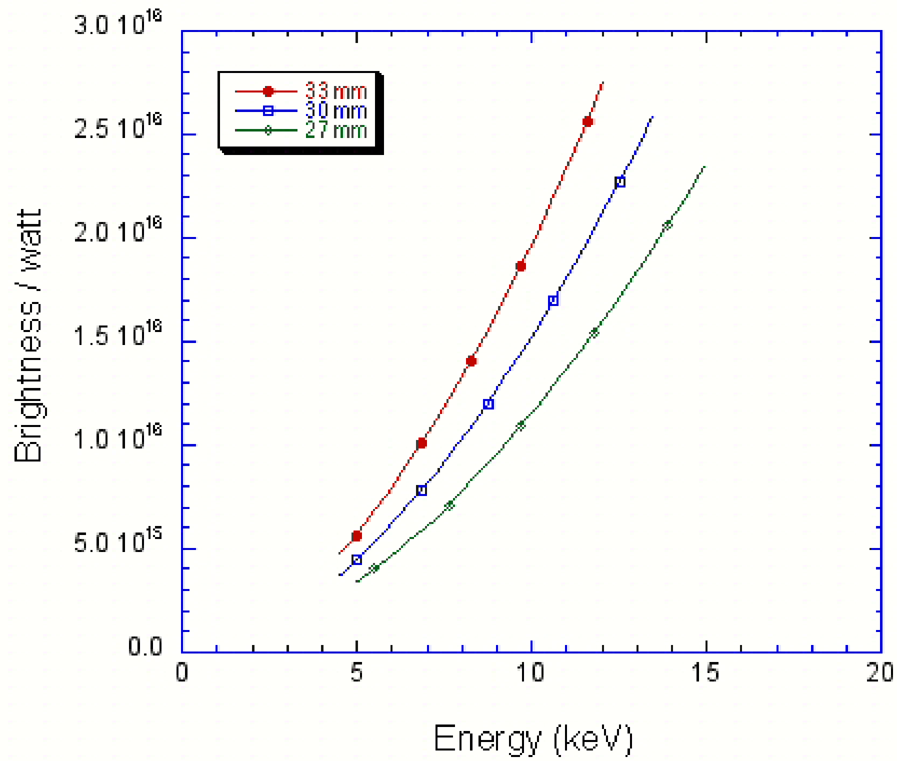



Figure 2. The brightness per unit power generated by various undulators as a function of energy of the first harmonics. When front-end heat load handling capability becomes an issue, it is important to provide the brightness at lowest power loads. Parameters are same as figure 1.

The strategy to acquire state-of-art undulators for HERIX involves some risk. We plan to hedge this risk by adopting an approach, which consists of ***"stimulate, follow, push, and decide"*** steps. The deadline for placing purchase order for planar magnetic undulators is 18 months before the start of operations, based on our written communication with commercial vendors. This period includes the procurement, construction, shipping and magnetic tuning. Therefore, we are under no pressure to make a final decision until the summer of 2003. Until then, we will stimulate the APS undulator group to pursue the superconducting undulator technology, the accelerator scientists to extend the straight section, and engineering group to come up with a solution to the high heat load problems. The key factors in our decision making process are:

Maximum length of the straight section
Minimum magnetic gap (MMG)
Front-end high heat load engineering
Status of the progress with superconducting undulator prototype, and
Optimizations of the magnet structure.

Since IXS-CAT is the first "second generation" beamline at the APS, we are confident that APS will have a stake to provide us with the most powerful beam possible.

We anticipate that APS will provide a total of 6 or 8 undulators, depending on the final length of the straight section, proper front-end to sustain the heat load, and availability of short period (12 ±2 mm) period superconducting undulator.

# 3 Beamline Design

The proposed beamline, designed to satisfy the scientific program outlined above, will carry out experiments in two different regimes:

1. Medium energy resolution experiments in the 5-15 keV region with 10 to 500 meV resolution. This spectrometer has been dubbed MERIX, for Medium Energy Resolution Inelastic X-ray scattering. Experimental requirements include an energy tunable beamline and horizontal and vertical diffraction capabilities. In particular, it is necessary that the transition metal K edges be covered.
2. High energy resolution experiments with sub-meV resolution with an incident energy in the 25-28 keV region. This spectrometer has been dubbed HERIX, for High Energy Resolution Inelastic X-ray scattering. Experimental requirements include the highest possible resolution and an adequate momentum transfer range.

It is not possible to design a single insertion device that is optimized for both energy ranges and we have therefore chosen to work with two separate devices, each optimized for the appropriate regime as discussed above. The proposed beamline is composed of three stations, including the two end-stations, as shown in Figure 3.

Note, the high-incident-energy of the high-resolution spectrometer is dictated by the energy resolution requirement. The preferred method of energy analysis is to use a back-scattering bent silicon analyzer, which determines the achievable resolution. There is a reverse correlation between the incident energy, and maximum achievable resolution. In order to reach the sub-meV level the incident energy must be higher than 25 keV. Therefore, we plan to design an undulator with a short enough period, consistent with the minimum achievable gap at the APS, to give a first harmonic in the range of 25-32 keV. Appendix A lists the key Work Breakdown Structure and associated timeline for this project.

## 3.1 Beamline Layout

The basic beamline philosophy is simplicity, reliability and ease of operation. Based on the first 5 years of experience of APS operations, we have decided to implement the following structure:

1. Tandem undulators, optimized for HERIX and MERIX.
2. A high heat-load pre-monochromator.
3. Focusing mirrors.
4. A white beam compound refractive lens (to collimate the beam for increased performance of the downstream optical elements).
5. Channel-cut silicon monochromators for medium-incident-energy-resolution.
6. An "in-line" cryogenically cooled tunable monochromator will be used for high-resolution monochromatization.
7. The MERIX and HERIX spectrometers - housed in separate stations.

The layout shown in Figure 3 below is a conceptual implementation and has been reviewed by a committee of experts from the APS, ESRF and SPring-8. A list of key beamline components is shown in Appendix B.

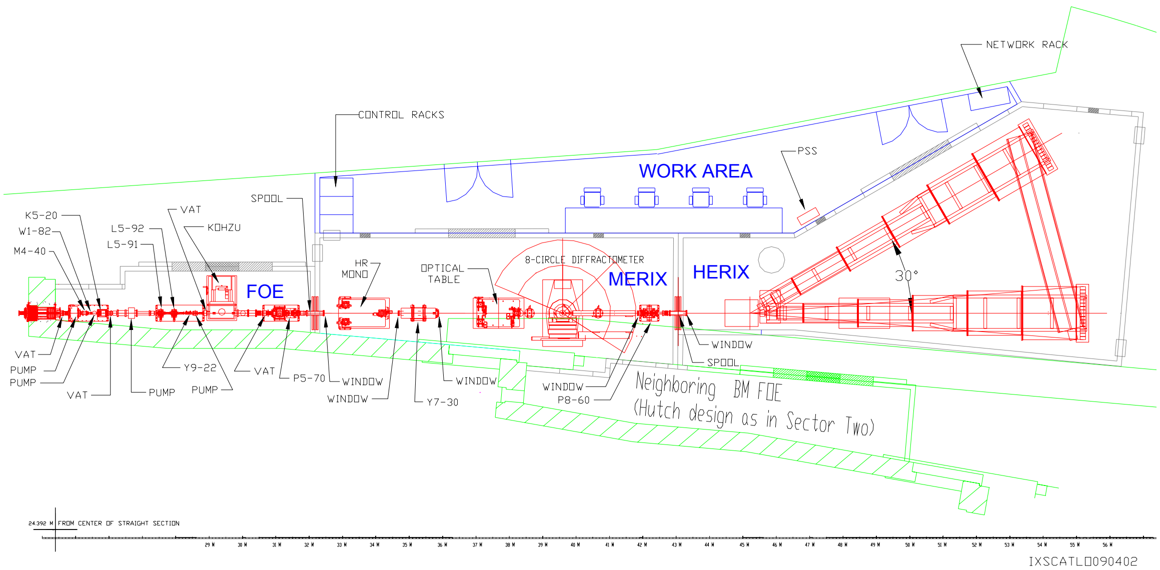



Figure 3. Plan view of the IXS beamline. See Figure C1 in Appendix C for more details.

Most of the components are APS standard components. Station A (FOE) is a white beam station and houses the high-heat-load monochromator. The FOE houses the beam-defining components, like the slits and a white beam refractive lens for collimation; in addition it houses the bremsstrahlung stop and a monochromatic photon shutter. Station B (MERIX) is a monochromatic station and houses the high-resolution monochromators followed by a focusing mirror. The MERIX spectrometer is placed in this station. The monochromatic photon shutter for the next station is located here. Station C (HERIX) is also a monochromatic station and houses the HERIX spectrometer. A work-area enclosure is planned to encompass the two monochromatic stations for operating the beamline.

## 3.2 Instruments

The high-heat-load pre-monochromator will be a double-crystal water-cooled diamond. The angular acceptance of diamond at 30 keV is around 6 microradians. The opening angle of the undulator radiation is typically around 12 microradians. However, there are published reports that this divergence can be reduced to under five microradians. Currently, a white-beam-collimating Be compound refractive lens is installed at Sector 3 of the APS. The performance of the lens has encouraged us to stick to the diamond high heat load monochromator.

The high-resolution monochromator for the MERIX instrument will be a fixed exit, double channel-cut instrument to keep the beam height constant when scanning energy. There will be little if any noticeable heat load on this device. A number of them will be made for the various required incident energies and will be of modular design such that swapping in and out will be straightforward. Such monochromators are routinely used in synchrotron radiation beamlines, and will not be discussed further here.

The high-resolution monochromator for sub-meV resolution in the 25-30 keV range, however, merits some discussion, as there is no such instrument currently available. The advantages of using a tunable "in-line" monochromator for inelastic scattering, as opposed to the single-back scattering crystal as adopted at the ESRF and SPring-8 are; a highly accurate energy scale, the ease of tunability, a clean resolution function for the incident beam, a convenient environment for the sample chamber, and few constraints on the analyzer container for low-momentum-transfer measurements.

The main disadvantage is the lower throughput compared to a backscattering monochromator. Cooling the crystals to liquid nitrogen temperatures can mitigate this difficulty. This concept has recently been tested at the APS, and the expected increases were realized. Currently, such a monochromator is under design at SRI-CAT, and we expect to take advantage of this implementation at IXS-CAT.

The MERIX spectrometer will be designed to perform polarization dependent measurements. This can be accomplished by having both vertical and horizontal diffraction capabilities with an 8-circle diffractometer. The expected sample-analyzer distance will be 1m and 2 m. For the resonance experiments, a different analyzer will be required for each absorption edge. Existing technology utilizes various Si or Ge reflections and energy transfer is scanned by varying the Bragg angle of the analyzer. In addition, we are presently pursuing the option of going closer to back-scattering to take advantage of the increased angular acceptance of crystals under such conditions. We plan to have a suite of analyzers, made of Si, Ge, $Al_2O_3$, and $LiNbO_3$, so that many atomic resonance energies can be reached. In such cases, energy scans are performed by scanning the temperature of the analyzer and maintaining near back-scattering conditions. Such methods allow scan ranges of 10-20 eV. The incident beam can be tuned continuously.

### 3.3 Essentials for the Success of the Overall Beamline Design

The critical features that will determine the success of the IXS-CAT are:

1. The maximum length of the straight section.
2. The availability of the number of undulators.
3. Availability of the superconducting (SC) undulator.
4. Cryogenically cooled monochromator for the HERIX instrument.
5. Performance of the sapphire analyzers.
6. Overall layout for flexibility.

1. The length of the straight section is to be extended to accommodate four insertion devices of standard length. Early simulations and machine studies show that this might be possible with some constraints like limiting the minimum vacuum chamber gap. We will try to ease this limitation by using 3.3-cm-period devices for MERIX and the SC device for HERIX.

2. We expect to have access to several devices. For example, one possible scenario is: 10-m-long straight section, 2.5 m taken by SC undulator, and the remaining 7.5 m for three 3.3-cm-period devices. If the SC undulator is not available, then we expect to get three or four sets of the 1.5-cm-period device, as well as three or four sets of the 3.3-cm-period. Whatever the maximum length of the straight section, we expect to fill it with undulators and swap them per user period of three months. This will not apply to the SC undulator due to cryogenic systems.

3. Our fallback position if SC undulators are not available is to procure undulators with a 1.5 cm period. Our earlier communication with companies indicates that this is possible.

4. The tests carried out at sector 3 indicate that a factor 3 or 4 is gained by cooling the higher order reflection of the nested monochromator (the inner pair) to liquid nitrogen or helium temperatures, respectively. We plan to use a liquid-nitrogen-cooled monochromator for ease of operation and cost. The issues regarding vibration isolation are being addressed at sector 3, and early experience shows that going under 1 meV at 25 keV will be possible.

5. The R&D for sapphire analyzers has started at sector 3. Our early experience with backscattering sapphire crystals indicates that we can achieve high angular acceptance, and moderate energy resolution with a 2-inch-diameter crystal. We are now in the process of acquiring these crystals for manufacturing analyzers to be tested by summer 2003.

6. The beamline is designed more or less similarly to the sector 3 ID beamline, and using proven methods reduces the risks involved. All the necessary R&D is being conducted at sector 3.

The overall success of IXS-CAT will be measured by the number of photons per required bandpass on the sample and the number of photons at the detector scattering from a standard sample like Plexiglas. Therefore, only the degree of success rather than success itself is in question here.

### 3.4 Anticipated Performance

#### 3.4.1 MERIX

For undulator A, with the first harmonic at 8 keV, it is anticipated that the output flux will be 1.5 x $10^{14}$ photons $s^{-1}$/eV. Once this is monochromatized with a channel cut monochromator, the expected flux incident on a sample is 1 x $10^{13}$ photons $s^{-1}$/100meV. This is two orders of magnitude larger than the incident flux presently obtainable at the NSLS inelastic beamline, X21 and is a factor of 10 higher than achievable at other APS beamlines with temporary inelastic set-ups.

#### 3.4.2 HERIX

The small period undulators should supply 3 x $10^{13}$ photons $s^{-1}$/eV at 25.5 keV. After passing through the high heat-load-monochromator and the in-line high resolution monochromator it is anticipated that the incident flux on the sample will be 2 x $10^9$ photons $s^{-1}$/0.5meV with the crystals at room temperature and 8 x $10^9$ photons $s^{-1}$/0.5 meV with the implementation of liquid nitrogen cooling. A comparison of these fluxes with the other third generation high resolution beamlines is given below:

| **Beamline** | **Flux on sample** |
|---|---|
| HERIX (R.T.) | 2 x $10^9$ ph $s^{-1}$ / 0.5 meV |
| HERIX (77 K) | 8 x $10^9$ ph $s^{-1}$ / 0.5 meV |
| 3ID (APS) | 3 x $10^8$ ph $s^{-1}$ / 1.3 meV |
| ID16 (ESRF) | 3 x $10^8$ ph $s^{-1}$ / 0.8 meV |
| BL35XU (SPring-8) | 3 x $10^9$ ph $s^{-1}$ / 1.5 meV |

Clearly, the HERIX instrument will represent a significant advance on the state-of-the-art for inelastic scattering beamlines at the very highest resolution.

# 4 R & D Requirements

The current IXS-CAT proposal requires the following research and development programs to reach its full potential:

1. Extension of the straight section of the APS storage ring
Lattice simulation studies need to be carried out, accompanied by machine studies in order to implement a longer straight section that is consistent with APS long-term storage ring upgrade goals like lower emittance and higher stored currents.

2. Undulator vacuum chambers for longer straight sections
Current vacuum chambers are designed to accommodate 5 m long undulators. A new design is needed to accommodate longer straight sections.

3. Superconducting Undulator
HERIX experiments require an undulator which delivers ~25 keV in the first harmonic. To achieve this with a K of around 1 requires a device, which has a magnetic field of about 0.8 Tesla at 1 cm gap and 1.5 cm-period. We expect APS to conduct required R&D and deliver the prototype for IXS.

4. Front-end with high-heat-load handling capacity
While the anticipated heat load at 100 mA seems to be within the limits of current safe operation envelope, it is necessary for APS to look into modifications in the current front-end design to accommodate higher stored current in the storage ring that may take effect in the near future.

5. Cryogenically-cooled high-resolution monochromator for HERIX
To improve the performance of the HERIX monochromator, it is necessary that Sector 3 instrumentation program includes the development of a cryogenically-cooled monochromator. We need a turn-key system ready for a user program. The prototyping and specifications for a vendor-built system, procurement, installation and commissioning is expected to be performed by SRI-CAT personnel.

6. Dynamically bent analyzer for HERIX and MERIX
The possibility of using either a 6 or 10 m analyzer requires the availability of analyzer mounting mechanisms capable of bending to different radii. The current developments at Sector 3 of SRI-CAT are encouraging, and therefore, we anticipate that mechanical parts for the analyzers for HERIX and MERIX instruments will be developed by Sector 3.

7. Sapphire analyzers for MERIX
In order to benefit from increased angular acceptance near back-scattering angles, we plan to use a number of different analyzers, in particular sapphire, which will be developed by SRI-CAT.

## 5 List of IXS-CAT Members

Most of the IXS-CAT personnel have extensive experience at synchrotrons around the world, including the Advanced Photon Source, the National Synchrotron Light Source and the ESRF. Many of them have experience in constructing and operating beamlines at a third generation sources in general, and at the APS in particular. Further, there is a strong component in the CAT of personnel with prior inelastic x-ray scattering experience, and indeed includes many of the pioneers in the field. The CAT is further strengthened by the presence of a number of scientists with a proven track record in the development of instrumentation for inelastic scattering. Finally, the breadth of the scientific interests present amongst its membership, including traditional solid-state physics, soft condensed matter, and geophysics and protein biology, enhances the strength of the CAT. Below is a list of the personnel involved in the project, listed alphabetically by institution.

<u>U. Akron, Ohio</u>
A. Sokolov (Dept. of Polymer Science)

<u>Albert Einstein College of Medicine</u>
D.L. Rousseau

<u>Argonne National Laboratory</u>
E. Alp (APS)
A. Macrander (APS)
R. Osborn (MSD)
H. Sinn (APS)
W. Sturhahn (APS)
T. Toellner (APS)

<u>Brookhaven National Laboratory</u>
D. Gibbs (Dept. of Physics)
J.P. Hill (Dept. of Physics)
C.-C. Kao (NSLS)
S. Shapiro (Dept.of Physics)

<u>U. California, San Diego</u>
S. Sinha

<u>Carniege Institute of Washington</u>
David Mao

<u>Cornell University</u>
P. Abbamonte (CHESS)

U. Illinois at Chicago
P. Montano (Dept. of Physics)
J.C. Campuzano (Dept. of Physics)

U. Illinois at Urbana-Champaign
T.-C. Chiang (Dept. of Physics)
I.K. Robinson (Dept. of Physics)
M. Klein (Dept. of Physics)
M. Salamon (Dept. of Physics)
R. Simmons (Dept. of Physics)

Lucent Technologies
E. Isaacs
P. Platzman

Massachusetts Institute of Technology
S.-H. Chen (Dept. of Nuclear Engineering)
Y. Lee (Dept. of Physics)

Northeastern University
A. Bansil
P. Champion
T. Sage

Oak Ridge National Laboratory
B.C. Larson (Solid State Division)

U. Pennsylvania
T. Egami (Dept. of Materials Science)

Princeton U.
Z. Hassan (Dept. of Physics)

Stanford University
M. Greven (Dept. of Applied Physics)
Z.-X. Shen (Dept. of Physics)

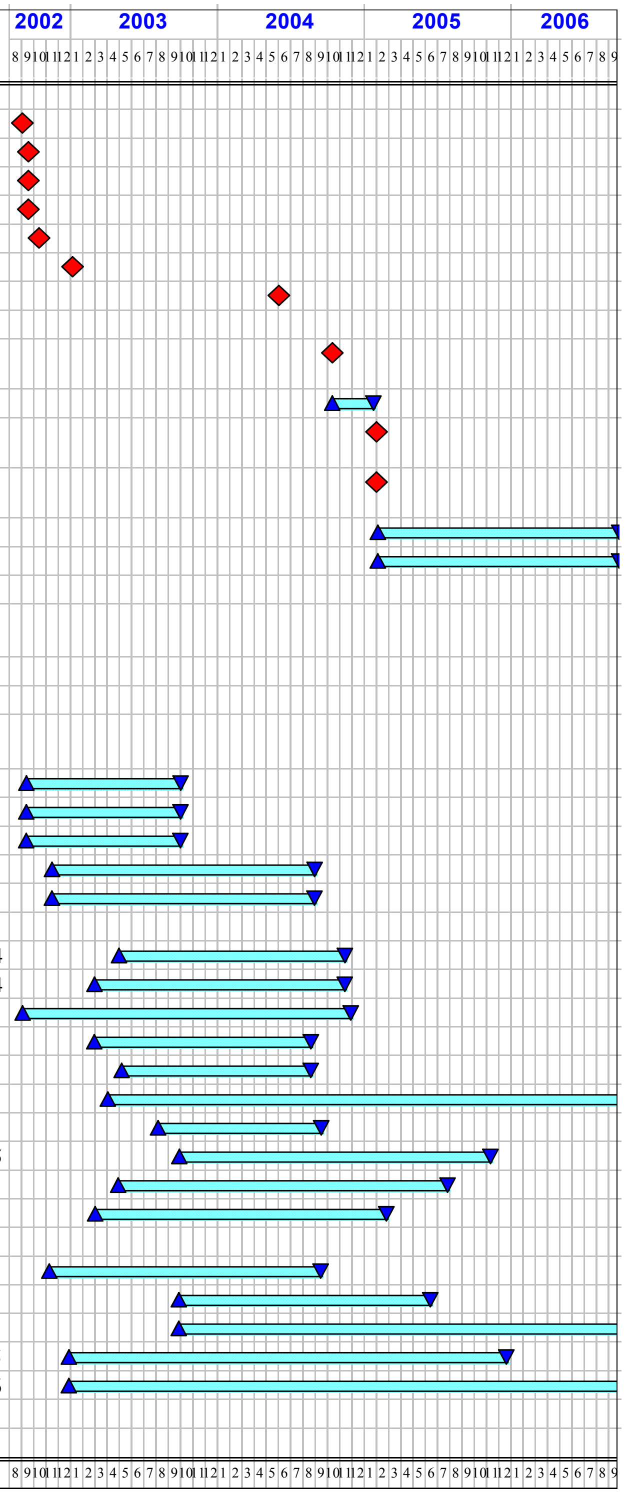
SUNY-Stony Brook
P. Stephens (Dept. of Physics)

U. Tennessee
A. Eguiluz (Dept. of Physics)

W. Michigan Universtiy
C. Burns (Dept. of Physics)

# Appendix A. Overview of WBS and Major Milestones

| WBS | Activity Name | Start Date | Finish Date |
|---|---|---|---|
| **1.1** | **Project Planning** | | |
| 1.1.1 | CDR | 9/6/02 | |
| 1.1.2 | Management Plan | 9/20/02 | |
| 1.1.3 | Safety Plan | 9/20/02 | |
| 1.1.4 | Cost & Schedule Plan | 9/20/02 | |
| 1.1.5 | MOU | 10/18/02 | |
| 1.1.6 | PDR | 1/10/03 | |
| 1.1.7 | FDR | 6/4/04 | |
| 1.1.8 | Commissioning | | |
| 1.1.8.1 | Shielding Verification Station A | 10/15/04 | |
| 1.1.8.2 | Commissioning Station A | 10/18/04 | 1/28/05 |
| 1.1.8.3 | Shielding Verification Station B | 2/3/05 | |
| 1.1.8.4 | Shielding Verification Station C | 2/4/05 | |
| 1.1.8.5 | Commissioning Station B | 2/7/05 | 9/29/06 |
| 1.1.8.6 | Commissioning Station C | 2/7/05 | 9/29/06 |
| **1.2** | **SR Modifications** | | |
| **1.3** | **Straight Section Vacuum Chamber** | | |
| **1.4** | **Insertion Devices** | | |
| **1.5** | **Front End** | | |
| **1.6** | **Beamline Stations & Infrastructure** | | |
| 1.6.1 | Station A... | 9/16/02 | 10/3/03 |
| 1.6.2 | Station B... | 9/16/02 | 10/3/03 |
| 1.6.3 | Station C... | 9/16/02 | 10/3/03 |
| 1.6.4 | Beamline Utilities ... | 11/18/02 | 9/3/04 |
| 1.6.5 | Work Area Enclosure... | 11/18/02 | 9/3/04 |
| **1.7** | **Beamline Optics** | | |
| 1.7.1 | White Beam Slits... | 5/5/03 | 11/19/04 |
| 1.7.2 | Focusing Lens... | 3/3/03 | 11/19/04 |
| 1.7.3 | Primary Monochromator... | 9/9/02 | 12/3/04 |
| 1.7.4 | Integral Shutter... | 3/3/03 | 8/27/04 |
| 1.7.5 | Monochromatic Shutter... | 5/12/03 | 8/27/04 |
| 1.7.6 | Monochromatic Mirrors... | 4/7/03 | 8/31/07 |
| 1.7.7 | Support Tables... | 8/11/03 | 9/24/04 |
| 1.7.8 | Optical Tables... | 10/3/03 | 11/18/05 |
| 1.7.9 | Vacuum Hardware... | 5/5/03 | 8/5/05 |
| 1.7.10 | Be Windows... | 3/10/03 | 3/4/05 |
| **1.8** | **General Instrumentation** | | |
| 1.8.1 | PSS... | 11/15/02 | 9/24/04 |
| 1.8.2 | EPS... | 10/6/03 | 6/24/05 |
| 1.8.3 | Controls... | 10/6/03 | 8/31/07 |
| **1.9** | **MERIX Instrumentation** | 1/6/03 | 12/30/05 |
| **1.10** | **HERIX Instrumentation** | 1/6/03 | 12/29/06 |
| **1.11** | **Lab Office Module (LOM)** | | |
| **1.12** | **Contingency** | | |



## Appendix B. List of Key Beamline Components

| Name | Distance from Source (m) | Description |
|---|---|---|
| | | |
| VAT | 24.593 | Front End Exit Valve |
| PUMP | 25.055 | Ion pump |
| M4-40 | 25.278 | Water cooled mask |
| W1-82 | 25.412 | Be window |
| PUMP | 25.561 | Ion pump |
| K5-20 | 25.660 | Tungsten bremsstrahlung collimator |
| VAT | 26.028 | Beamline Isolation Valve |
| | | |
| PUMP | 26.657 | Ion pump |
| | | |
| L5-91 | 27.416 | White beam slits |
| L5-92 | 27.837 | White beam slits |
| Y9-22 | 28.061 | Be Compound Refractive Lens |
| PUMP | 28.584 | Ion pump |
| | | |
| VAT | 28.919 | Vacuum isolation valve |
| KOHZU | 29.640 | Kohzu monochromator |
| VAT | 30.602 | Vacuum isolation valve |
| | | |
| P5-70 | 31.091 | White beam stop/ monochromatic shutter |
| SPOOL | 32.175 | Shielded transport between stations |
| WINDOW | 32.433 | Be window |
| | | |
| HRMONO | 33.561 | High resolution monochromator |
| | | |
| WINDOW | 34.597 | Be window |
| Y7-30 | 35.220 | Mirror |
| WINDOW | 35.865 | Be window |
| | | |
| WINDOW | 41.834 | Be window |
| P8-60 | 42.189 | Monochromatic shutter |
| SPOOL | 43.055 | Shielded transport between stations |
| WINDOW | 43.307 | Be window |
| | | |

## Appendix C. Beamline Layout and Ray Diagrams

# Figure C1  IXS Beamline Layout Plan & Elevation View

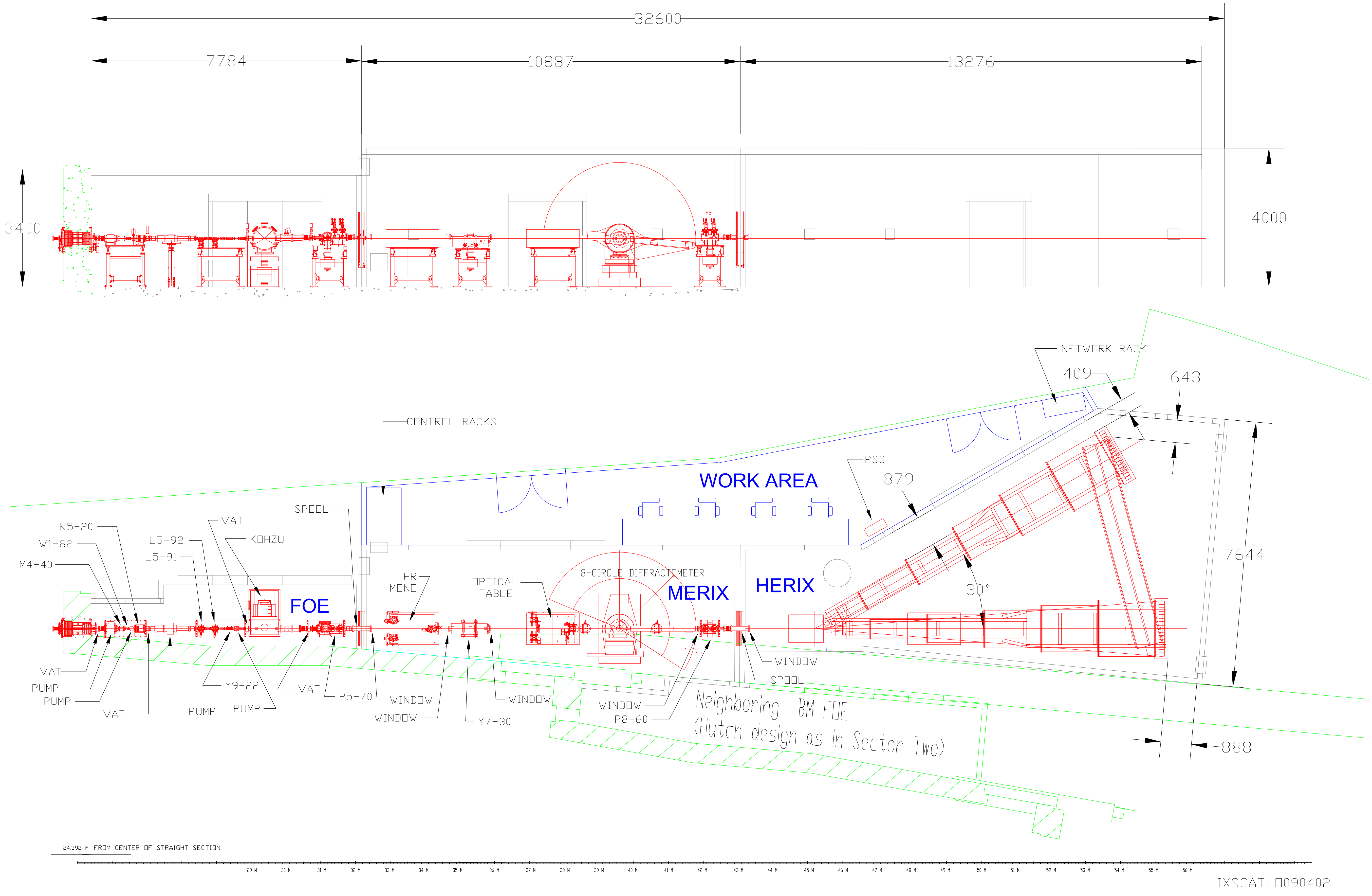
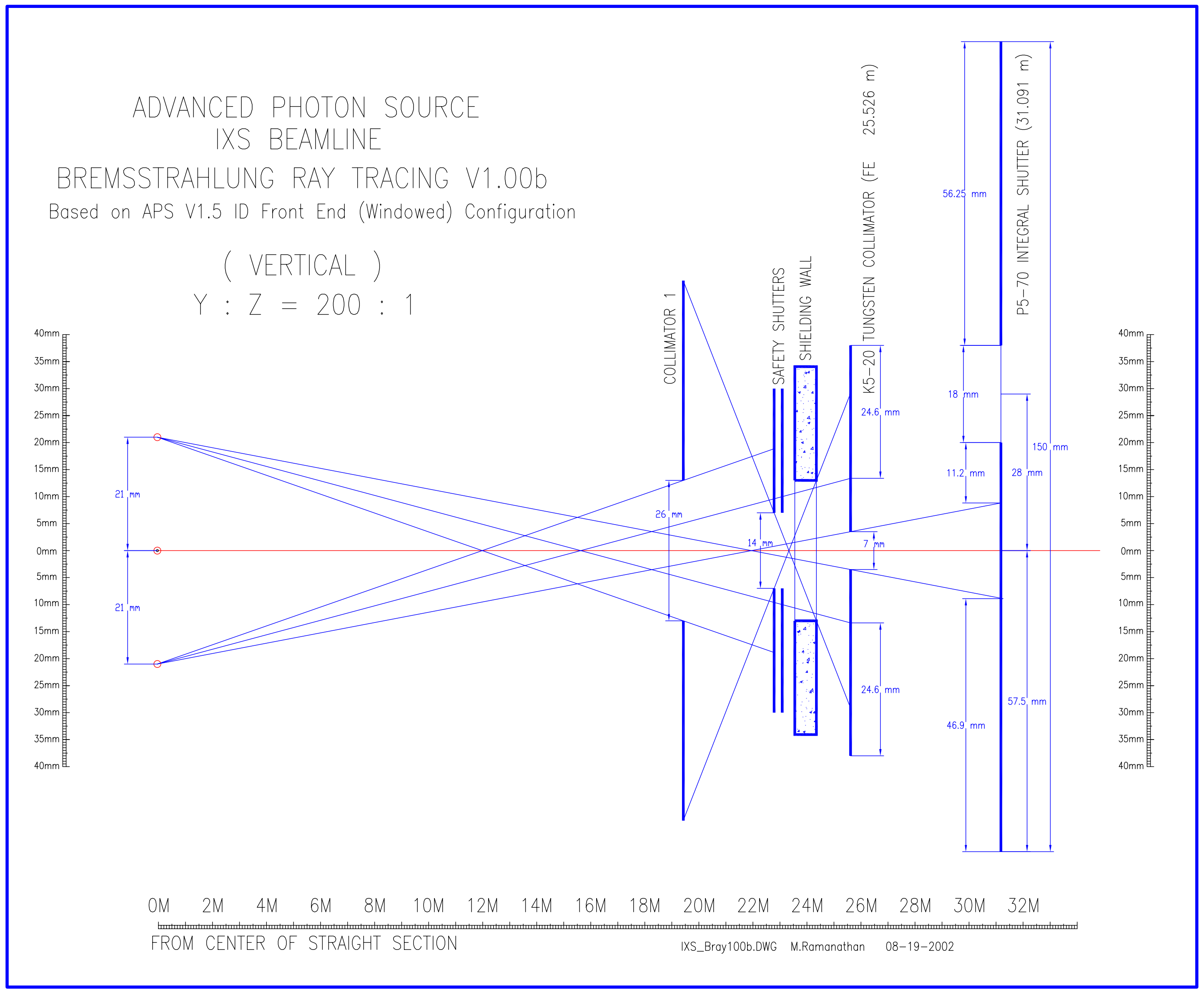


Figure C2. Bremsstrahlung Ray Tracings



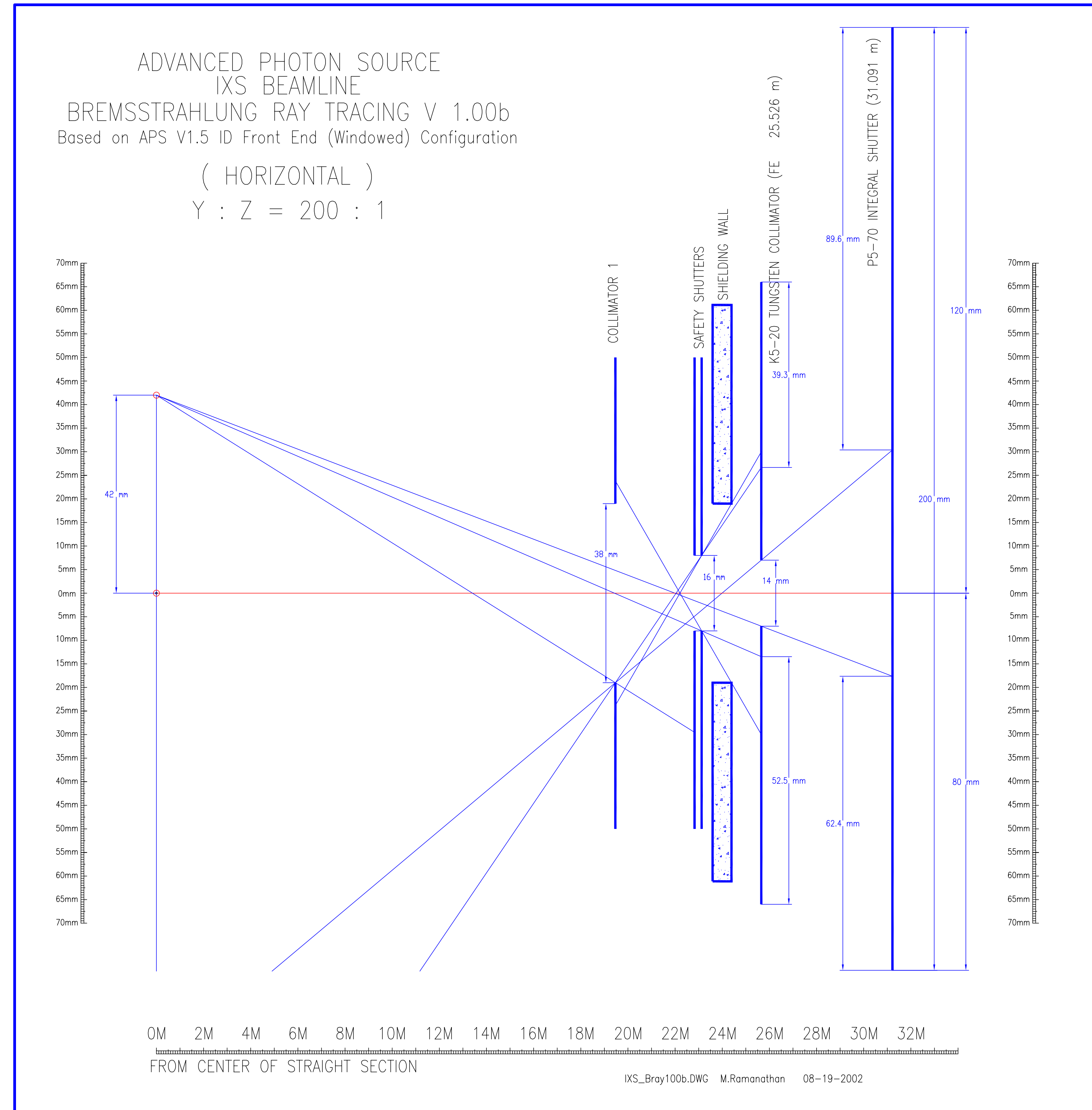



Figure C3. Synchrotron radiation Optical Aperture Ray Tracings